BIOMASS EQUATIONS FOR *Pinus brutia* IN NORTHERN ISRAEL

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SUMMARY

In the late 1960's *Pinus brutia* Ten. replaced the native Aleppo pine (*Pinus halpensis* Mill.) as the principal afforestation species in the hilly Mediterranean region of northern Israel. While the native Aleppo pine had many advantages, its poor growth form and susceptibility to Matsucoccus attack caused foresters to shift to species with resistance to the scale. We developed equations for above-ground biomass of individual trees. Trees of different ages (15 to 27 years) were felled and sampled. Linear, logarithmic, and non-linear regression equations were developed, with height and either diameter at breast height (1.37 m) or the product of diameter squared and height as predictor variables.

INTRODUCTION

In the late 1962's *Pinus brutia* Ten. replaced the Aleppo pine (*P. halepensis* Mill.) as the principal afforestation species in the hilly Mediterranean region of northern Israel. While the Aleppo pine, long regarded as the native pine of the Galilee (Weitz, 1974) had many advantages, its poor growth form and susceptibility to the Matsucoccus scale caused foresters to shift to resistant species. *Pinus brutia* is native to the eastern Mediterranean basin (Panetsos, 1981; Alemdag, 1962), and has replaced *P. halepensis* in planting on most sites.

The goal of afforestation in Israel has been amenity plantings and erosion control, but the commercial potential of these forests for charcoal and construction timbers has not been overlooked (Kolar, 1980; Gottfried, 1982). Only a modest amount is known, however, about their inherent productivity. As part of an effort to stratify productivity potential on different soil types, we developed regression equations for predicting above ground biomass of individual *Pinus brutia* trees.

MATERIALS AND METHODS

Individual trees of different ages (15 to 27 years) on contrasting Terra Rossa soils (derived from dolomitic limestone) and Rendzina soils (derived from hard chalk) were felled. Within each soil type we selected stands representing high and medium site classes. Plots were established in seven stands, and two or three trees were sampled in each plot for a total of seventeen trees. Average characteristics of the entire sample are given in Tables 1 and 2.

Each tree was felled at groundline and total height, midcrown height and live crown length were measured on the felled specimens. Discs were removed from the stem at groundline, breast height (1.37 m.) and at 1 m intervals thereafter. Bole wood and crown portions were weighed green in the field. Approximately a 20% sample of the crown was weighed green and then separated into needles, cones, and two classes of branches in the field and transported to the lab for determination of dry weight. Branches over 5 cm dob at the basal end were classed as coarse branches; smaller diameter material was regarded as fine branches. All samples were dried at 65°C.

Green and dry weights for individual tree components used in the analysis result from expanding the proportionate subsample weights to the whole component. Three forms of regression models were developed for green and dry weights of the whole tree (live above ground biomass), bole wood, crown (live crown), needles, fine branches, and coarse branches. The models fitted by least squares regression were linear, logarithmic, and exponential (non-linear) using the SYSTAT microcomputer software. Independent variables used were diameter at breast height (dbh), height (HT), dbh squared (D^2), and dbh squared times height (D^2H). Significance tests were at the 0.05 level.

Table 1. Ranges in characteristics of sample trees in northern Israel.

n	Age (year)	Diameter* (cm)	Total Height (m)
17	15-29	8.1-23.2	7.0-14.8

* Diameter breast height - 1.37 m.

Table 2. Average green and ovendry weights of sample tree components, in kg.

	Whole Tree	Bole	Crown	Needles	Fine Branches	Coarse Branches
Green	178.835	102.137	76.698	22.349	17.621	37.330
Dry	87.712	50.540	37.172	10.591	8.455	17.887

RESULTS

Multiple regression equations for green weights with dbh, DH, D^2 and D^2H were all significant; the adjusted R^2 ranged from 0.992 for bole weight to 0.866 for fine branches. The coefficients of the independent variables, however, were not significant, with one exception. Height was a significant predictor of coarse branch green weight. Linear models for dry weights explained significant amounts of the variance in the data (adjusted R^2 values ranged from 0.883 to 0.945). However, no regression coefficients were significant.

All logarithmic models were significant. In all cases but one, $\log_e$ (dbh) gave the highest adjusted R^2. Bole weight again showed a significant relationship to a variable that included height, in this case D^2H. The logarithmic equation using $\log_e$ (dbh) and $\log_e$ (D^2H) are given in Table 3. Logarithmic models for dry weights followed a pattern similar to green weights. All regressions were significant but models with $\log_e$ (dbh) explained the most variance. Again, the one exception was the bole weight where $\log_e$ (D^2H) had the highest R^2. Logarithmic equations are shown in Table 5.

Table 3. Biomass prediction equations for green weight of *Pinus brutia* in northern Israel using a logarithmic model (ln Y = a + b ln X; ln = natural logarithms; Y = green weight (kg), X = dbh (cm) or D^2H (cm^2.m).

Dep Variable	**(n)**	**Indep Variable**	**Intercept (a)**	**Slope (b)**	**Adjusted R^2**	**Standard error***
Total tree	(17)	DBH	-1.055	2.299	.982	0.103
Bole	(17)	DBH	-1.280	2.179	.967	0.132
Crown	(17)	DBH	-2.371	0.342	.957	0.171
Needles	(14)	DBH	-3.743	2.493	.960	0.169
Fine branches	(14)	DBH	-3.395	2.276	.870	0.293
Coarse branches	(14)	DBH	-3.349	2.532	.945	0.203
Total Tree	(17)	D^2H	-1.804	0.889	.969	0.135
Bole	(17)	D^2H	-2.074	0.854	.981	0.100
Crown	(17)	D^2H	-3.055	0.937	.911	0.246
Needles	(14)	D^2H	-4.256	0.925	.935	0.217
Fine branches	(14)	D^2H	-3.724	0.826	.806	0.357
Coarse branches	(14)	D^2H	-3.917	0.945	.934	0.224

* Standard error of estimate in $\log_e$ form

Two exponential models were fitted to the data, with and without an intercept. Generally the model without an intercept converged to a solution faster. The model with intercept for coarse branches would not converge to a solution due to rounding error. The exponential models without constants are given in Table 4.

Exponential models for dry weights are shown in Table 6. Again, models without intercepts were more stable than models with intercepts included.

Table 4. Biomass prediction equations for green weight of *Pinus brutia* in northern Israel using an exponential (non-linear) model (Y = exp (BO + B1 x DBH).

Dep variable	(n)	BO	(SE)	B1	(SE)
Total Tree	(17)	2.980	(0.108)	0.142	(0.006)
Bole	(17)	2.575	(0.189)	0.133	(0.010)
Crown	(17)	1.910	(0.339)	0.155	(0.017)
Needles	(14)	0.711	(0.160)	0.150	(0.008)
Fine branches	(14)	0.378	(0.303)	0.155	(0.015)
Course branches	(14)	0.734	(0.214)	0.176	(0.010)

* SE = Standard error

Table 5. Biomass prediction equations for dry weight of *Pinus brutia* in northern Israel using a logarithmic model (ln Y = a + b ln X; ln = natural logarithms; Y = dry weight (kg), X = dbh (cm) or D^2H (cm^2.m).

Dep Variable	(n)	Indep Variable	Intercept (a)	Slope (b)	Adjusted R^2	Standard error*
Total Tree	(17)	DBH	-1.812	2.314	.980	0.108
Bole	(17)	DBH	-2.046	2.200	.975	0.115
Crown	(17)	DBH	-3.138	2.478	.957	0.173
Needles	(14)	DBH	-4.556	2.516	.963	0.165
Fine branches	(14)	DBH	-4.214	2.304	.853	0.318
Coarse branches	(14)	DBH	-4.190	2.566	.922	0.248
Total Tree	(17)	D^2H	-2.559	0.894	.965	0.143
Bole	(17)	D^2H	-2.826	0.859	.982	0.097
Crown	(17)	D^2H	-3.841	0.944	.915	0.242
Needles	(14)	D^2H	-5.101	0.936	.945	0.201
Fine branches	(14)	D^2H	-4.533	0.834	.787	0.382
Coarse Branches	(14)	D^2H	-4.771	0.958	.912	0.264

Table 6. Biomass prediction equations for dry weight of *Pinus brutia* in northern Israel using an exponential (non-linear) model Y = exp (BO + * DBH).

Dep Variable	(n)	BO	(SE)	B1	(SE)
Total Tree	(17)	2.114	(0.094)	0.151	(0.005)
Bole	(17)	3.566	(0.072)	0.081	(0.002)
Crown	(17)	1.132	(0.133)	0.158	(0.007)
Needles	(14)	-0.119	(0.242)	0.155	(0.012)
Fine branches	(14)	-0.494	(0.257)	0.162	(0.013)
Coarse branches	(14)	-0.137	(0.274)	0.184	(0.013)

DISCUSSION

Despite a small sample size and the broad range of sites sampled, the logarithmic and exponential prediction models explained large amounts of variability. While we were constrained by time and other limitations from felling additional trees on which to test the reliability of these equations, we are using published data from *Pinus brutia* growing in southern Turkey (Sun *et. al.*, 1980) to test our equations. The additional 14 trees in this data set represent older (38 to 107 years) and larger trees (maximum dbh = 39.8 cm, maximum height 18.3 m) than our sample. Preliminary results suggest that our equations are reasonable predictors of whole tree and bole wood weights, both green and ovendry. Crown weights, however, are not well-predicted by our equations as the older trees in Turkey carry about the same size crowns as the younger trees in Israel.

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